is the ratio of atmospheric depletion, and Beer's Law in modified form is

$$\frac{I}{I_o}=a^m, \qquad (2)$$

where a is the coefficient of atmosphere transmission, and m, the air mass, is the exponent.

The factor $\frac{I}{I_o}$ has been plotted against air mass, m, by Kimball for several stations in figure 1 of his paper, "Atmospheric transmission coefficients at various altitudes," page 2, MONTHLY WEATHER REVIEW, January 1935. The discussion is continued by Hand in the December 1937 issue; Hand's figure 15, page 427, gives graphically values of a in equation 2 for air masses from 1 to 5.

AEROLOGY IN THE HURRICANE WARNING SERVICE

By GORDON E. DUNN

[Weather Bureau, Jacksonville, Fla., February 1939.]*

The great improvement in the scope and accuracy of the advisories and warnings of tropical storms issued by the United States Weather Bureau has been recognized quite generally, especially by the public on the South Atlantic and Gulf coasts. However, business interests and the general public in this area, encouraged by the constantly increasing efficiency of the Bureau's hurricane warning service, demand still further refinements which, at present, are difficult and often impossible to meet. Most of the senior forecasters will remember when occasionally, because of insufficient land and especially marine observations, hurricanes became "lost" for several days at a time until finally an isolated ship report or a Mexican coastal station would locate the storm many hundreds of miles from the forecaster's projected position. Although the hurricane winds would not often exceed 75 miles in width, in the first two decades of this century hurricane warnings would fly occasionally along many hundred miles of coastline before the storm eventually reached the coast.

The present highly efficient [1] collection of ships' observations in the Gulf of Mexico, Carribbean Sea and South Atlantic [2] Ocean at 7 and 1 a. m. and p. m. E. S. T., and the system of direct calls to ships for special observations during storm conditions should be largely credited to the late E. B. Calvert, formerly Chief of the Forecast Division of the United States Weather Bureau. The ship reporting system now in effect was discussed by Calvert before the 1935 meeting of the American Geophysical Union (**1**). With the increase in the frequency of observations and the number of vessels included in the system, together with the Coast Guard and Bureau of Lighthouses, the Weather Bureau can accurately locate, most of the time, the position of the storm and its direction and rate of movement.

However, there are other more complex forecasting problems brought about by the notoriously erratic behavior of tropical storms. They may slow to almost a complete standstill for a day or so, may make several turns in their paths, and may even make a complete loop. Some of these erratic movements are apparently pure freaks, such as in the case of the November 1935 storm, but most of them occur at the time a storm leaves the deep easterly current on the southern periphery of the great Azores anticyclone and commences its northward journey through the changeable upper-air currents over and to the east of the southeastern United States. When these latter currents are light, the storm will move very slowly, and when they are changeable the movement of the disturbance likely will be erratic.

Mitchell (**2**) states, "All tropical storms in the Northern Hemisphere apparently seek to move northward at the first favorable opportunity * * *. Any tropical storm will recurve into a trough of relatively low pressure that may exist when the tropical storm arrives in the same region * * *. No storm will break through and recurve until it reaches a region where south or southwest winds prevail and relatively low pressure to the northward is shown on the weather map."

Mitchell (**3**) has also discussed the influences of anticyclones on the direction of movement of tropical cyclones, and Bowie (**4**) has given several examples. Mitchell's conclusions seem, in the main, to be substantiated by the greatly increased observational material of today. Subnormal pressure along and immediately off the Atlantic coast is usually indicative that the normal or at least frequent easterly current aloft in the Florida-Bahamas region has been replaced by a south to west current. However, pressure conditions in front of an advancing hurricane are often flat and indefinite, and often deceptive as regards conditions aloft, consequently a more true and dependable picture of upper air conditions in the entire hurricane region is necessary before any real forecasting of changes in rate and direction of movement of these storms can be attempted.

This article is intended to present the status of aerology in the hurricane warning service at the present time. Upper-air information is obtained from observed cloud types and directions, pilot-balloon ascensions, airplane and radiosonde observations.

Cloud observations are the one source of upper-air information which has shown a deterioration during the past 20 years. At the present time, exclusive of regular Weather Bureau stations within the United States, only two stations, San Juan, Puerto Rico, and Swan Island in the western Caribbean, include cloud data in their regular surface observations. This unfortunate situation has come about through economies which have forced the elimination of precipitation as well as cloud data and through the use of an abbreviated figure code which does not include precipitation, cloud data, or the 3-hourly barometric changes and characteristics. All forecasters engaged in hurricane warning work have considered clouds, especially the cirrus types, important and helpful. The Cuban Jesuit meteorologists, from Viñes to the present time, who have contributed considerably to our knowledge of these storms, have emphasized the importance of clouds in the theoretical and practical treatment of hurricanes. The Rev. Father Eulogio Vazquez, S. J., Belen College, has recently reached further interesting conclusions (as yet unpublished) regarding the relation of upper-air currents to the movement of tropical storms which deserve consideration and trial by other meteorologists. The inclusion of cloud data in all possible land surface reports

*The author, now located at the Weather Bureau office in Chicago, Ill., has revised this paper, with the assistance of Warren O. Johnson of the Jacksonville office, to November 1940.

[1] Since the beginning of the war, there necessarily has been considerable decrease in the number of ship reports, because foreign as well as United States ships had been participating.

[2] The term "South Atlantic" as used in this paper applies to the south portion of the North Atlantic Ocean, or, more specifically, that portion south of latitude 35° N.

should receive the early attention of the United States Weather Bureau. Cloud data contained in cooperative ship reports are considered to be of too doubtful accuracy at present to be utilized.

Meteorology does not yet know the complete answer to the problem of hurricane origin and development. Many students of this subject are attempting to apply air-mass analysis to tropical meteorology, and there has been an increasing number of efforts in the past few years to apply some system of frontal analysis to regions transversed by tropical storms and to the tropical disturbances themselves. Some of these attempts have seemed quite promising. Edna Scofield (5) has recently summarized these viewpoints regarding fronts in the Tropics, and has listed nearly everything published on this subject. Naturally, there are numerous conflicting theories and opinions, with, up to the present time, insufficient free air-data in the Tropics to prove or disprove most of them. Why do some wave disturbances in the Tropics never develop and others reach hurricane intensity? Of course, this question is, as yet, inadequately answered even in extra-tropical regions, and the answer to this and related problems seems locked in the upper air, but airplane or radiosonde observations should provide the meteorological world with the key. Free-air data have been obtained through airplane ascensions by the Navy at Pensacola, Fla., Coco Solo in the Canal Zone, and at St. Thomas in the Virgin Islands. The last two were temporarily discontined in 1940. St. Thomas is by far the best located for most study purposes, as Pensacola is too far north and Coco Solo too near the Equator. The United States Weather Bureau on two occasions maintained an airplane or radiosonde station at Miami, Fla., which is better situated for study than either Coco Solo or Pensacola, but it, unfortunately, has also been discontinued. The Navy, for several years, made airplane ascents at Guantanamo Bay, Cuba, which is very well located, but no longer does so The resumption of airplane or radiosonde observations at Miami and Guantanamo Bay would be valuable for purposes of research and study, and the establishment of several more observational points of like character is most desirable. [The Weather Bureau has now established a radiosonde station at Swan Island in the extreme western Caribbean.] A cursory examination of the St. Thomas airplane observations for only a short period will reveal frequent important changes in the amount of moisture present in the intermediate levels, and that the easterly current in this region is not one homogeneous air mass. In any possible future application in the Tropics of frontal analysis for general use in forecasting, there are indications that upper-air data may be fully as necessary here as in more northerly latitudes.

The Weather Bureau, in cooperation with the Massachusetts Institute of Technology, for the past 3 years has carried on a program providing for the release of sounding balloons during the passage of hurricanes over certain localities. However, the hurricanes have been rather uncooperative and no storm during this period has passed over Cuba where M. I. T. has maintained personnel and no hurricane has passed directly over any station in the United States where the Weather Bureau has maintained the necessary equipment. It is hoped that this project will be continued until soundings are finally obtained within a well-developed hurricane, as it is expected that the data so obtained will add materially to our knowledge of the structure of these storms.

However, it is in the extension of pilot-balloon stations that the greatest progress has been made during the past few years. Beyond the borders of the United States, the main source of this information is through the cooperation of the Pan American Airways. Most of these reports are received through the P. A. A. office in Miami, Fla., and placed on the hurricane teletype there, but some P. A. A. Mexican observations are placed on the teletype at Brownsville, Tex. Twice-daily balloon observations are plotted on Upper-Air Map A from the following regular airport stations of the United States Weather Bureau on the South Atlantic and Gulf coasts: Charleston, S. C.; Jacksonville, Tallahassee, Maimi, Key West, Tampa, Fla; Mobile, Ala.; New Orleans and Lake Charles, La.; and Houston and Brownsville, Tex. The inset maps on Upper-Air Map A do not extend south of Key West, Fla., and Brownsville, Tex.; therefore pilot-balloons runs from stations south of the United States are entered on this map in tabular form. Pilot-balloon observations are received twice daily from the United States Weather Bureau stations at San Juan, Puerto Rico, and Swan Island in the western Caribbean; also once or twice daily from the naval air stations at Pensacola, Fla.; Guantanamo Bay, Cuba; and Coco Solo, Canal Zone.

P. A. A. pilot-balloon runs are received as follows: Havana, Cienfuegos, and Antilla, Cuba, and Kingston, Jamaica, about one observation a day; San Julian, Cuba; St. Johns, Castries or Fort de France, and Port au Spain, in the Windward Islands; Macoris, in the Dominican Republic, and Merida, Mexico, each about 20 observations per month; Tampico and Vera Cruz or Tejeria, Mexico, and Managua, Nicaragua, about 15 observations per month. David, Panama, and Tacubaya, Hermosillo, Tapachula, Mexico City, and Mazatlan, Mexico, and La Guaira, Venezuela, Barranquillo, Colombo, and Georgetown, British Guiana, are received only occasionally. The locations of these stations are shown in figure 1. While it will be noted that some of these stations are not received regularly, P. A. A. is most cooperative and usually can furnish several special observations daily from any of their stations when a disturbance is in progress. Most P. A. A. observations are taken in the forenoon and usually the number received, except on Sundays, is sufficient to furnish a fair picture of the general upper-air situation.

The increased information concerning upper-air currents now available daily throughout the hurricane season is another of meteorology's debts to aviation. It is hoped that with transoceanic flying regular pilot-balloon ascensions may be made in the not too distant future from a few selected ships located at strategic points. Meanwhile, pilot-balloon stations at St. Georges,[3] Bermuda; Nassau, Bahamas; and on one or more of the outlying Bahama Islands would give the forecaster additional invaluable upper-air information.

The southeast Florida coast, probably one of the most vulnerable sections of the Atlantic and Gulf coasts within the Jacksonville forecast district, and at the same time containing one of the most insistent civic groups upon the question of very precise warnings, presents at times, because of the tendency of tropical storms to recurve in this latitude, certain difficult problems in forecasting. Any consequential further progress in more accurately forecasting recurvatures, in this area at least, can result only through additional pilot-balloon stations as indicated in the preceding paragraph to supplement those now available from the Antilles and Florida.

No upper-air map has yet been printed embracing the area covered by the hurricane warning service. During

[3] Received through courtesy of Pan American Airways from May 1938 to August 1939.

the 4 years since this service was established, the West Indian, Caribbean and Mexican reports have been tabulated in no particular order on the Upper-Air Map A used at Jacksonville, Washington, and other forecast centers. This method, obviously, gives a very unsatisfactory visual presentation of the airflow pattern over the area as a whole. As a makeshift, at Jacksonville, a more suitable map has been mimeographed. This map covers an area bounded on the north by latitude 30°, on the south by latitude 6°, and on the east and west by longitudes 60° and 100°. A number of these maps may be pasted side by side when several levels are desired. mimeographed maps and pasted side by side. Thus, if sufficient reports are available, the forecaster has before him the general airflow pattern in which the tropical storm may be moving.

In the following presentation particular instances of hurricane forecasting wherein aerological data proved useful are discussed with the aid of figures showing the upper winds at the 10,000-foot level. The September 1937 series in the Atlantic is quite simple, while the last two examples are somewhat more complex.

September 3, 1937, a. m., figure 2.—The 10,000-foot level chart on this date presents an approximation of normal

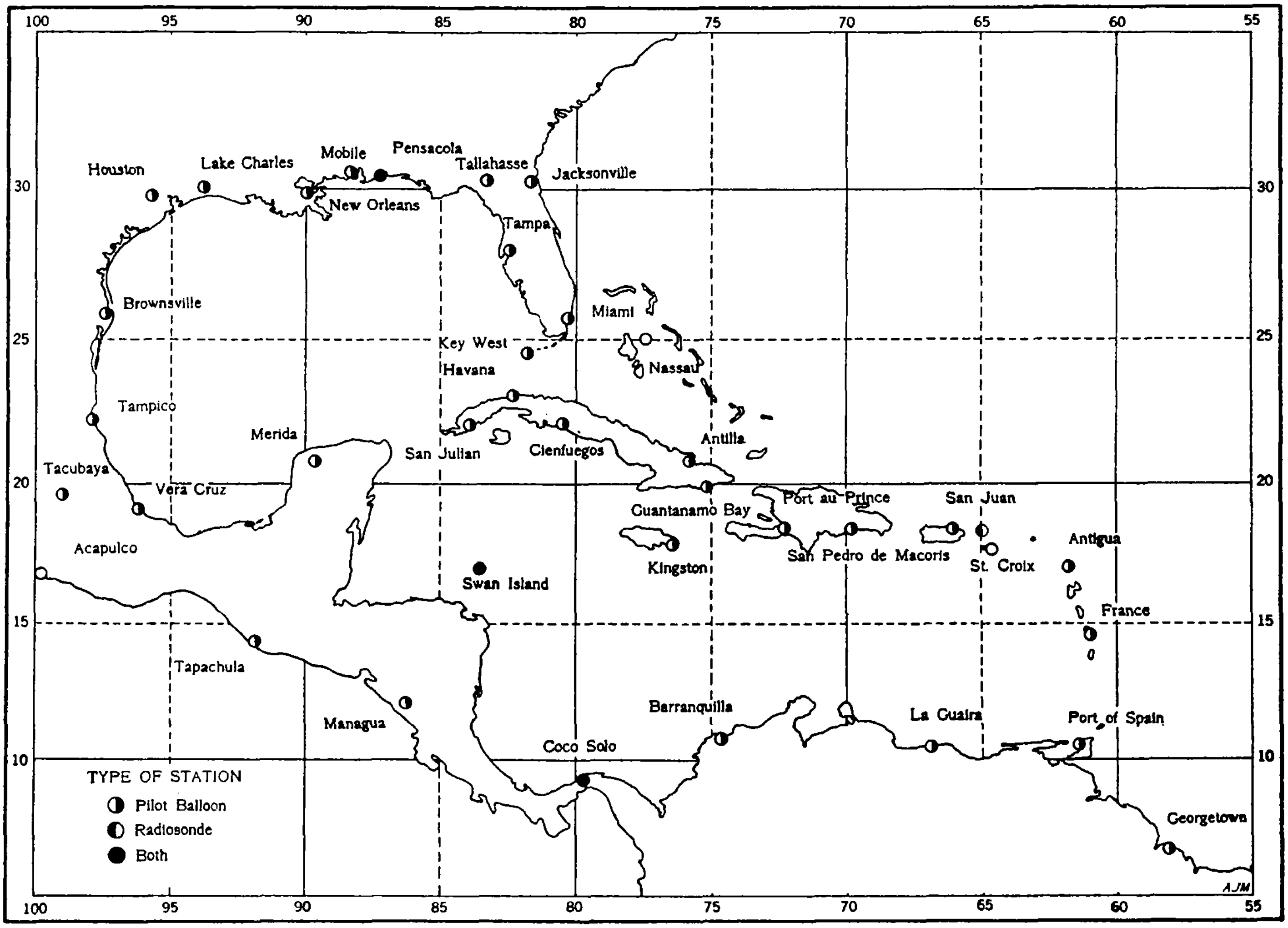

FIGURE 1.—Sources of pilot-balloon and airplane or radiosonde observations used in the Hurricane Warning Service.

During normal weather the tabulated data on Upper-Air Map A are inspected for possible abnormalities in wind velocities and directions. When conditions become unsettled, a 10,000-foot level map is prepared and the airflow pattern determined. The 10,000-foot level has been selected because that level is usually reached by a number of ascents sufficient to indicate with some measure of completeness the high level air currents. However, it has become apparent that at times air currents at still higher levels more closely approximate the direction and rate of movement of certain storms. In addition, the storms usually follow a path somewhat to the right of that indicated by the airflow pattern. When a well-developed tropical storm is in progress, levels at 2,000-foot intervals up to 14,000 feet are prepared on the upper-air conditions at this height for this time of year. East-northeast to east-southeast winds of 10 to 15 miles per hour prevail from near longitude 90° to east of longitude 60°, with a tendency to southeast and south winds west of 90°. Surface weather conditions on this date over the Caribbean Sea and the Gulf of Mexico also are about normal.

September 10, 1937, a. m., figure 3.—The 10,000-foot level chart of this date shows a strong anticyclonic circulation over the Gulf of Mexico, Florida, and Cuba, extending at least as far eastward as longitude 75°. This anticyclonic circulation has strengthened during the past 24 hours and fresh north-northwest winds now obtain over the entire Florida Peninsula. This north-northwest current is indicative of a low pressure trough at the 10,000-foot level some distance to the eastward, with an attendant southerly counter-current, which would permit a northerly recurve of any storm approaching from the east. At 7:30 a. m. this date a hurricane [4] was located in approximately latitude 21° N. and longitude 57° W. The first advisory on this storm from the Jacksonville district forecast center was issued at 3 p. m. this date, and in the amplification of this advisory to the press the forecaster, on the basis of the upper-air situation plus the general pressure distribution, indicated that the storm offered very little threat to the South Atlantic coast. The next advisory at 9:30 p. m. this same day contained the forecast, based largely on upper air information, as no ship reports close to the storm area had been received since morning, that the hurricane would move north or northeastward during the next few days and would pass to the east of Bermuda. This forecast was substantially verified. Subnormal surface pressure in the region of Bermuda was also indicative of a general northerly movement of this storm.

September 12, 1937, a. m., figure 4.—On this morning's weather chart the hurricane mentioned in the last paragraph was approaching the junction of latitude 30° N. and longitude 60° W., moving north-northwestward, while a second hurricane was central some 900 to 1,000 miles east of Antigua, Leeward Islands, moving only slightly north of west. An examination of the air currents at the 10,000-foot level this date shows a complete break-down of the normal easterly winds over practically the entire area. The only easterly wind encountered is south of latitude 10° at Coco Solo, C. Z. Consequently it is obvious that only an immediate, complete, and radical reversal of the upper-air winds prevailing on this date would permit a continuance of the general westerly movement of this second hurricane. Thus, 2 days before the hurricane reached the eastern limits of the weather map the forecaster was able to formulate an opinion, with considerable confidence, that this storm would make an early recurve.

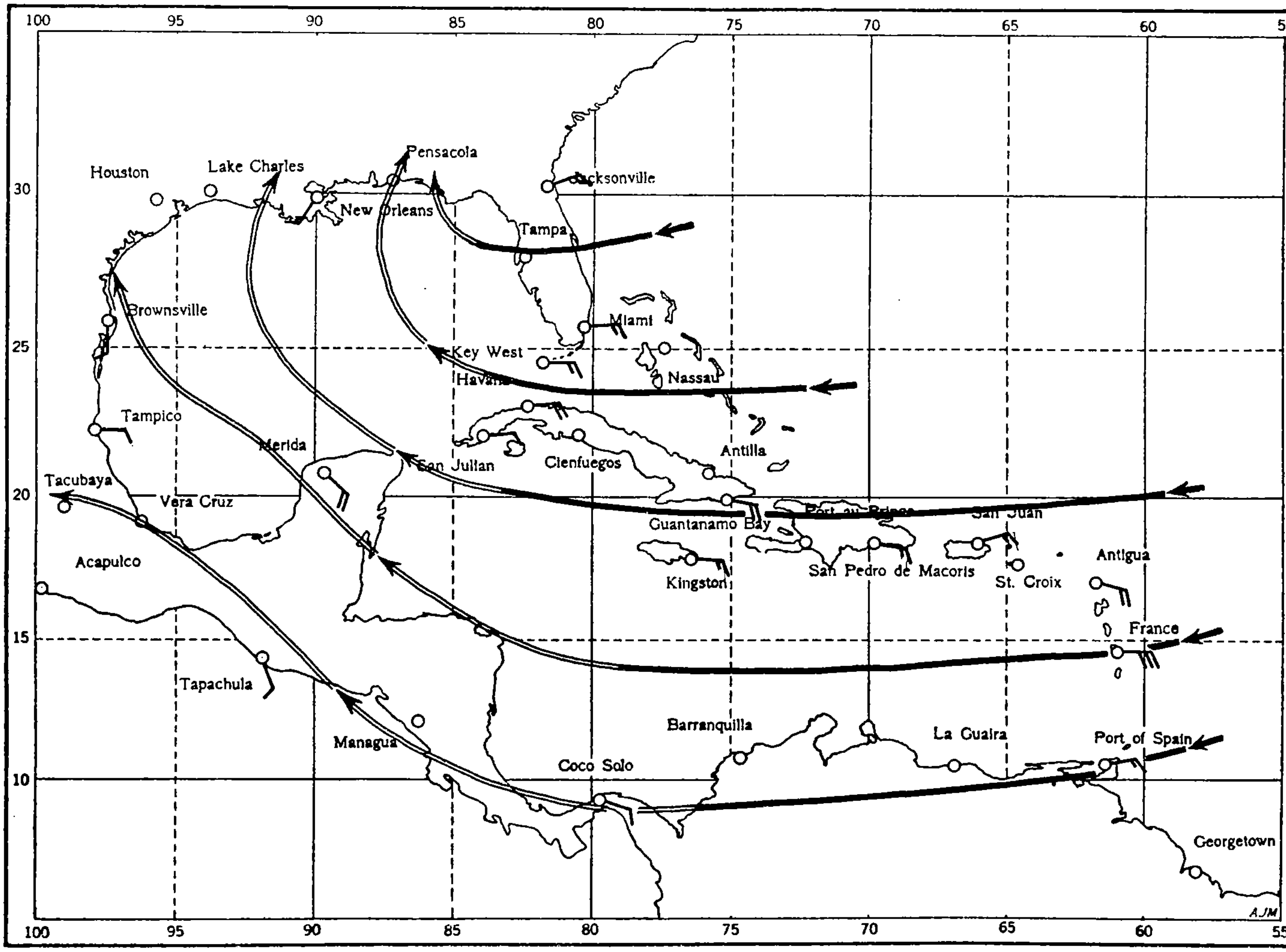

FIGURE 2.—Upper-air wind directions and velocities at the morning observation on September 3, 1937.

September 13, 1937, a. m.—Upper-air map not reproduced. The 10,000-foot level showed a strong anticyclonic circulation over Mexico and the western Gulf with the axis of the equatorial (southerly) current extending from the Gulf of Honduras to Florida. The Lesser Antilles was under the influence of the hurricane circulation with light (3 to 8 m. p. h.) northeast to north winds prevailing as far west as San Juan. On the entire map there was no evidence of any real easterly current which would carry the westward advancing hurricane past longitude 60°.

September 14, 1937, a. m., figure 5.—The hurricane reached its most westward position on this date, whereupon it began a sharp recurve to the east-northeastward.

[4] This storm was classified as definitely not of hurricane intensity in the synopsis of tropical disturbances of 1937, MON. WEATH. REV., December 1937, 65; p. 446. However, the S. S. *Winamac*, while the ship apparently was some distance from the center, reported force 11 (64–75 miles) in an observation radioed to the Jacksonville office. In the writer's opinion the storm was very likely of hurricane intensity for at least 24 hours and should be classified at least of "doubtful" if not of full hurricane intensity.

This direction of movement continued through the 15th, while on the 16th the storm began a north-northeastward movement which lasted for several days and brought it into the far northern latitudes. The 10,000-foot upper air chart on the 14th shows that the anticyclonic circulation continues over the northwestern Gulf, the equatorial break-through persists from Florida southwestward to the Yucatan Peninsula, and that the hurricane circulation is in evidence over the Lesser Antilles. The winds over Jamaica and eastern Cuba are extremely light. The center of the hurricane at 7 p. m. this date was at latitude 19° N. and longitude 58°–59° W., nearly on the eastern

The third hurricane of the month began a recurve to the northwest on the 20th, probably in a southeasterly current aloft. At this time the storm was 1,000 miles east of the Windward Islands and the current in which it moved was too far east to influence the upper air over the Lesser Antilles. Apparently the weakness, or more or less complete disintegration, of the normal easterly current aloft in the lower latitudes, which had permitted early recurves of the two earlier hurricanes was now situated farther to the east. It is thought that the weakening and strengthening of easterly winds aloft over the South Atlantic is associated with the intensity and

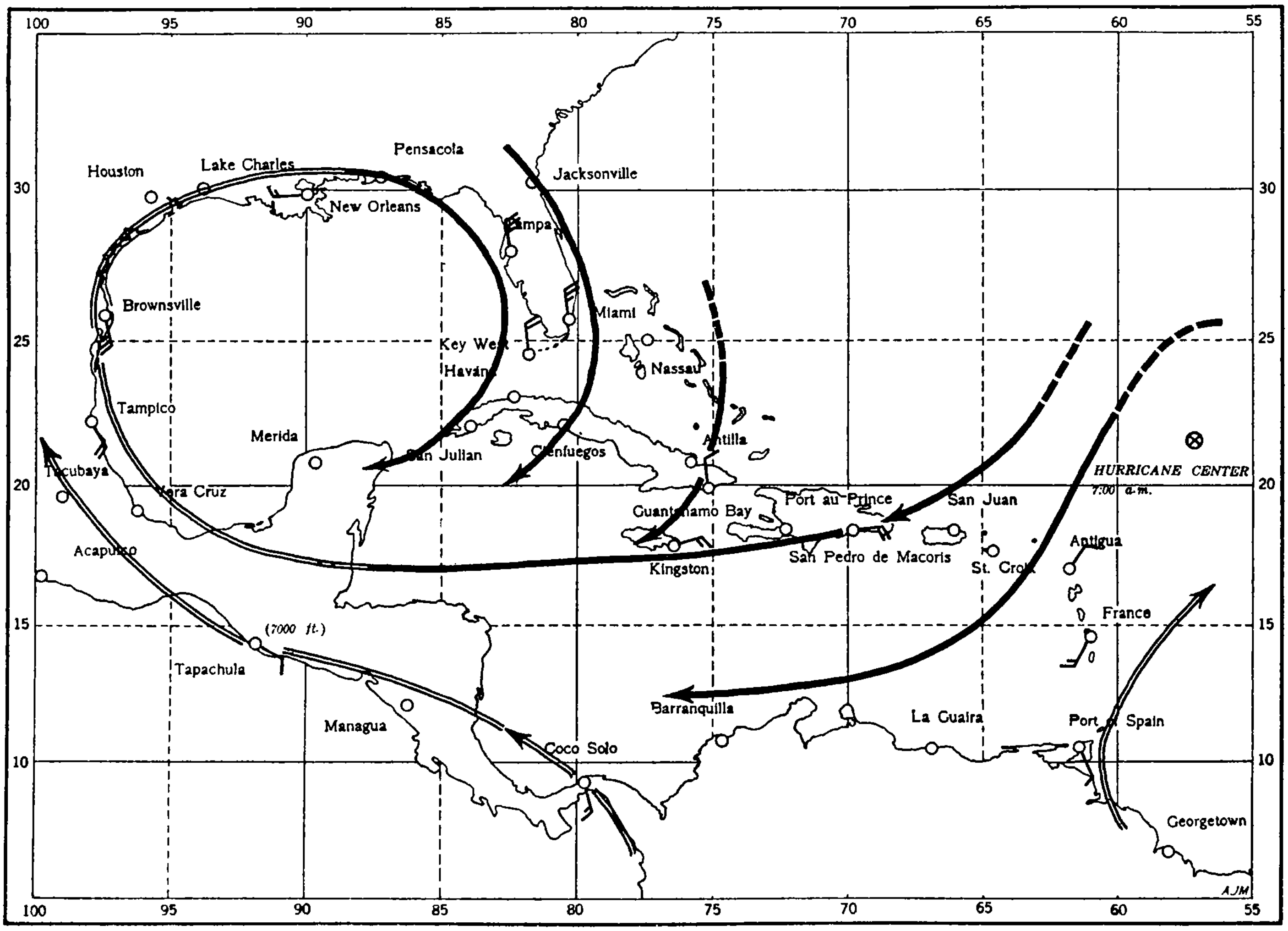

FIGURE 3.—Upper-air wind directions and velocities at the morning observation on September 19, 1937.

border of figure 5. Accepting the 12-mile northeast wind at San Juan as part of the hurricane circulation, one again finds no evidence of a real easterly current aloft west of the hurricane center, and consequently the storm is not subjected to further propulsion toward the west. During this period pressure was flat and somewhat below normal from the Atlantic coast eastward beyond the field of observation. A surface low pressure trough, with an attendant weak cold front through its center, extended from a point about midway between Cape Hatteras and Bermuda southwestward to the Florida Straits. Thus the early and sharp recurve of this hurricane 1,000 miles east of the cold front was not due to the barrier of any surface anticyclone, nor to the approach of a surface low pressure trough, but apparently solely to the wind currents aloft prevailing at the time.

location of the so-called Azores-Bermuda semipermanent anticyclonic cell. Azores pressures, unfortunately, are not available at the Jacksonville office for study in this connection.

The minor tropical disturbance of September 16–21, 1937, is most interesting and deserves a more intensive study from several standpoints, especially its frontal structure. This storm was a hybrid type, not uncommon in the Gulf of Mexico during September and October, with extra-tropical as well as tropical characteristics. Discussion in this paper, however, will be confined to the aerological situation in regard to this storm on the morning of September 18, 1937.

The first advisory on this disturbance was issued at 10 a. m. on the 17th, but some evidence of a circulation had existed for the preceding 24 hours. During the

16–17th, this storm was located in the southwestern and west-central Gulf, an area relatively unfrequented by weather-reporting vessels. On the morning of the 18th, the forecaster found himself in a rather puzzling situation. Ship reports were confined to the periphery of the disturbance, and as the deadline for the advisory approached the storm's intensity and position had to be obtained by deductions from these peripheral reports. It is also only fair to add that most of the balloon runs outside of the United States were not received until after the advisory was issued. An anticyclone was moving eastward over the Appalachian and Atlantic States and Cuba and western Florida, with east-northeast winds 24–27 miles per hour prevailing at New Orleans, La., and Houston, Tex. Since the storm has moved very slowly during the past 36 hours, it is evident that the tropical storm is not entirely within either the southwesterly current over the southeast Gulf or in the east-northeast current on the Louisiana and Texas coasts, but more probably the two opposite currents are two forces operating upon the storm and that the southwesterly current is the stronger. Although the velocities reported by the several stations in each air stream are about the same, it will be noted that velocities tend to increase as

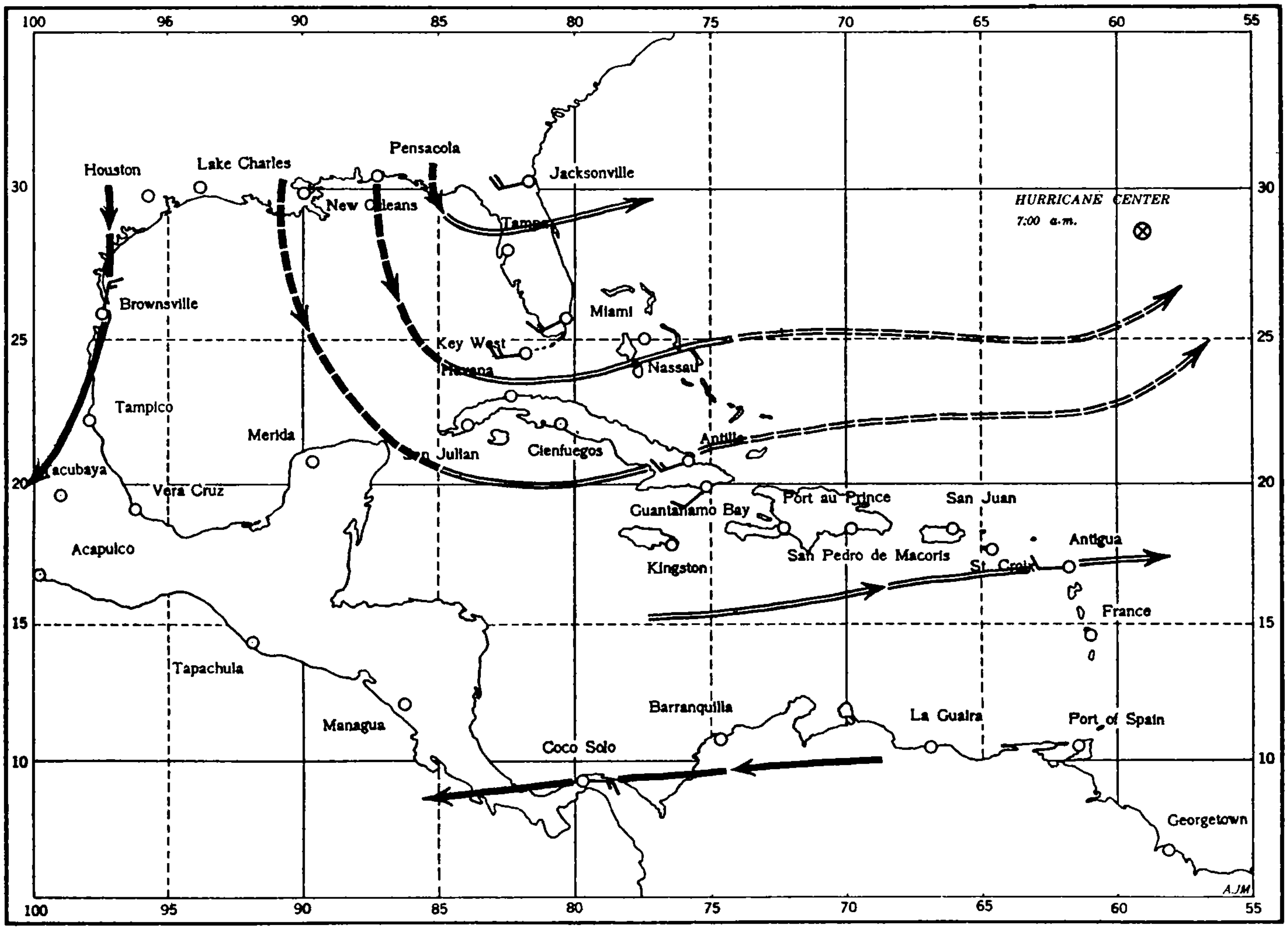

FIGURE 4.—Upper-air wind directions and velocities at the morning observation on September 12, 1937.

the 24-hour pressure fall on the Gulf coast was confined to the area between Brownsville, Tex., and the Mississippi coast. The forecaster finally concluded that the tropical disturbance was showing a slight westward or west-northwestward tendency and storm warnings were extended west of Galveston to Corpus Christi, Tex.

An examination of the upper-air situation at the 10,000-foot level (fig. 6) on the morning of September 18, 1937, discloses an anticyclonic circulation extending from Cuba and surrounding area eastward to Puerto Rico, with a current of southerly component probable over or a short distance east of the Leeward Islands. Over the Gulf of Mexico a deep trough or quasicyclonic circulation prevails with south and southwest winds from 22–28 miles per hour over the Yucatan Peninsula, extreme western the storm area is approached, and it is probable that balloon ascents an equal distance southeast of the storm center would show higher velocities than are reported at New Orleans and Houston. Furthermore, high cloud observations of the Gulf coast show that southwest and west winds are overrunning the east-northeast current prevailing at 10,000 feet, or rather on the west Gulf coast it is the somewhat cooler east-northeast current underrunning the tropical southwest current aloft. Cirrus, cirrostratus, and altostratus from the southwest are reported at Corpus Christi, Galveston, and Port Arthur, Tex., and Lake Charles, La. In fact, no high clouds from any other direction are reported on the Texas coast. At New Orleans, 6/10 altostratus from the east are reported, but as rain was falling it seems probable that some lower stratotype cloud other than altostratus prevailed. Pensacola, Fla., and Thomasville, Ga., report 10/10 altostratus from the west.

This is a more complex case than any of the previous situations, but whether the east-northeast upper-air current on the northwest Gulf coast is an actual force operating on the storm or merely part of the storm circulation, the integration of all upper-air factors present would seem to indicate a northeastward movement. During the next few days the storm moved northeastward to a point slightly above the mouth of the Mississippi River and thence eastward near the Gulf coast at a rate of about 6 to 8 miles per hour, and did not at any time reach full hurricane intensity.

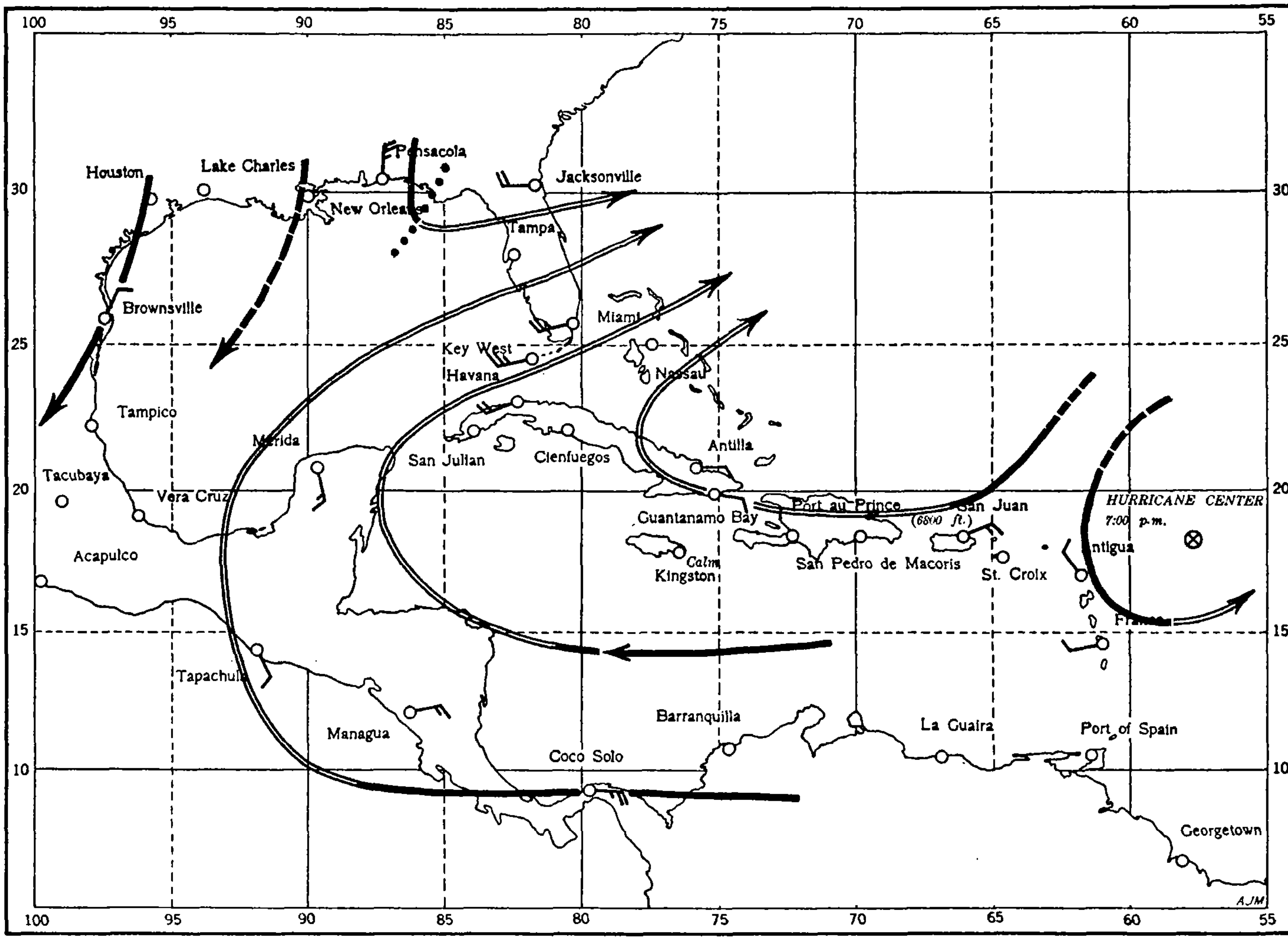

Figure 5.—Upper-air wind directions and velocities at the morning observation on September 14, 1937.

The last example of the possible use of upper-air information deals with the severe hurricane of September 17–22, 1938. Figures 7-10 show the 10,000-foot upper-air charts on the mornings of September 17 to 20, from the time the storm was approaching the Bahamas until it began to recurve. The chart (fig. 7) on the morning of September 17 shows an anticyclonic circulation from Antilla, Cuba, eastward, except that the hurricane circulation has begun to affect the Leeward and Windward Islands and probably Puerto Rico. This anticyclonic easterly current is the current in which the hurricane is moving. The equatorial "break-through" covers western Cuba and all of Florida, and the aerological situation as a whole indicates that the hurricane should recurve as it approaches this equatorial "break-through" some distance east of the Florida coast. Figure 8 shows the upper air situation at the 10,000-foot level on the morning of the 18th. The wind at Macoris, Dominican Republic, having backed slightly and increased, is now being influenced by the hurricane The winds over southern Florida and western Cuba still have a southerly component, but are backing and decreasing. Over the United States at 10,000 feet above sea level, anticyclonic conditions prevail over the western two-thirds of the country, and at 7 a. m. the southerly limit of the anticyclonic northerly current is a short distance north of Houston, Tex. From the Appalachians eastward a southwest tropical air current prevails. The general upper air situation still indicates a recurve east of the Florida coast.

The 10,000-foot chart (fig. 9) on the morning of September 19 shows the hurricane circulation extremely well. Winds over western Cuba and extreme southern Florida have backed to northeast and north. As these winds are light and are apparently continuing to back towards the north, one must conclude that they are not an extension of the easterly current in which the hurricane has been traveling, but merely a part of the hurricane circulation. From central Florida northward over the Atlantic States the moist tropical south-southwest air current continues. The anticyclonic circulation noted the day before over the

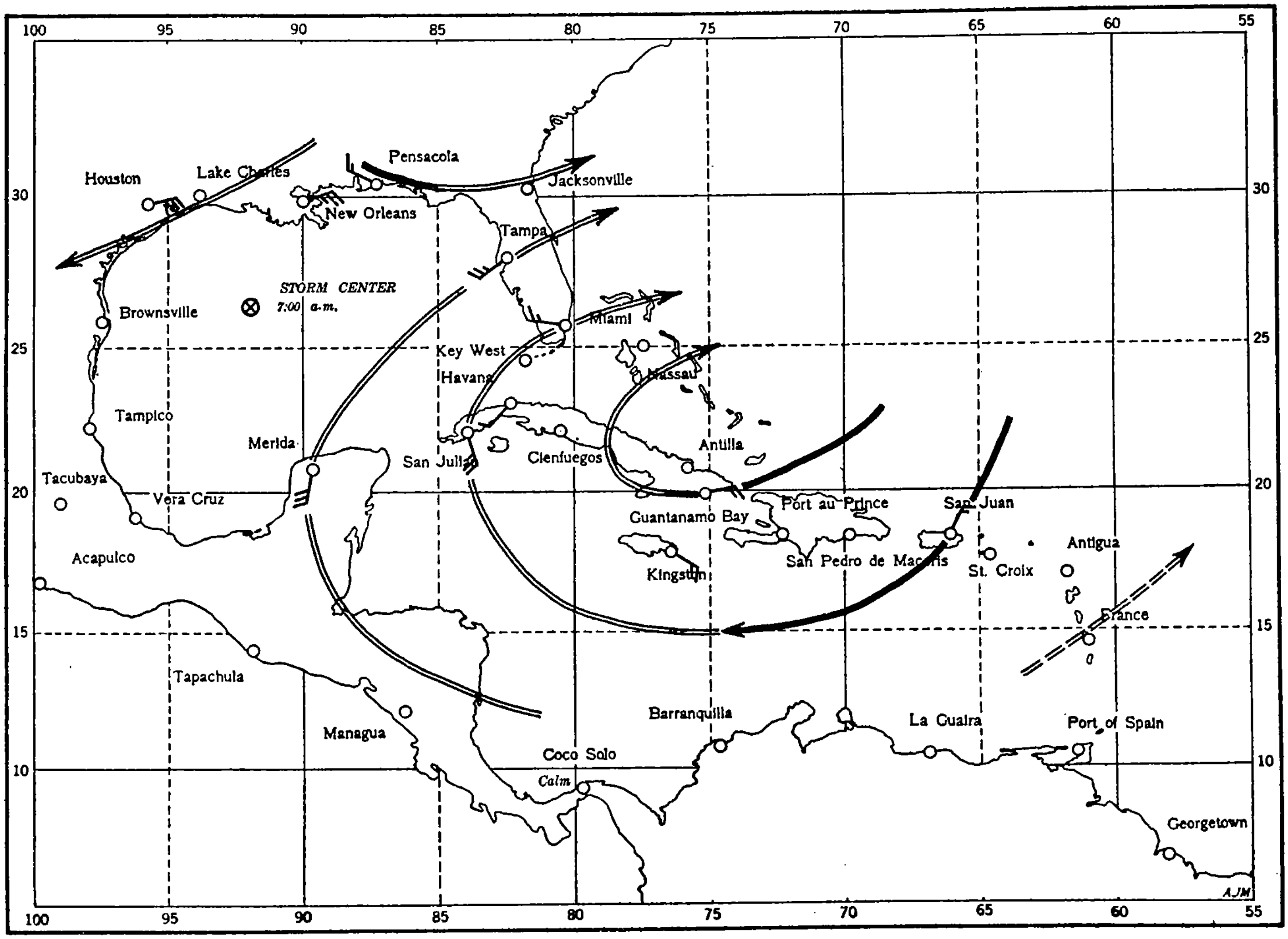

FIGURE 6.—Upper-air wind directions and velocities at the morning observation on September 18, 1937.

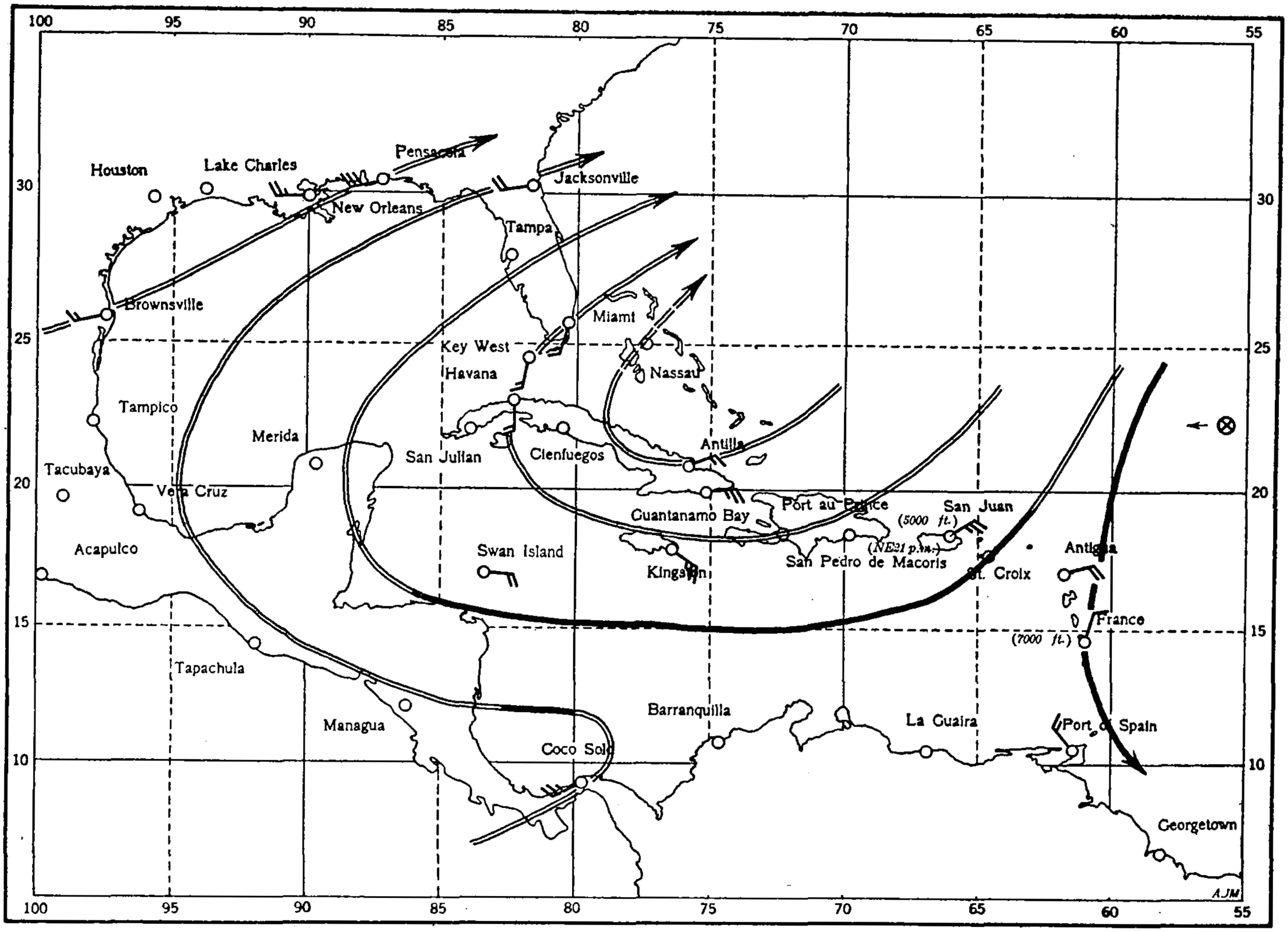

FIGURE 7.—Upper-air wind directions and velocities at the morning observation on September 17, 1938.

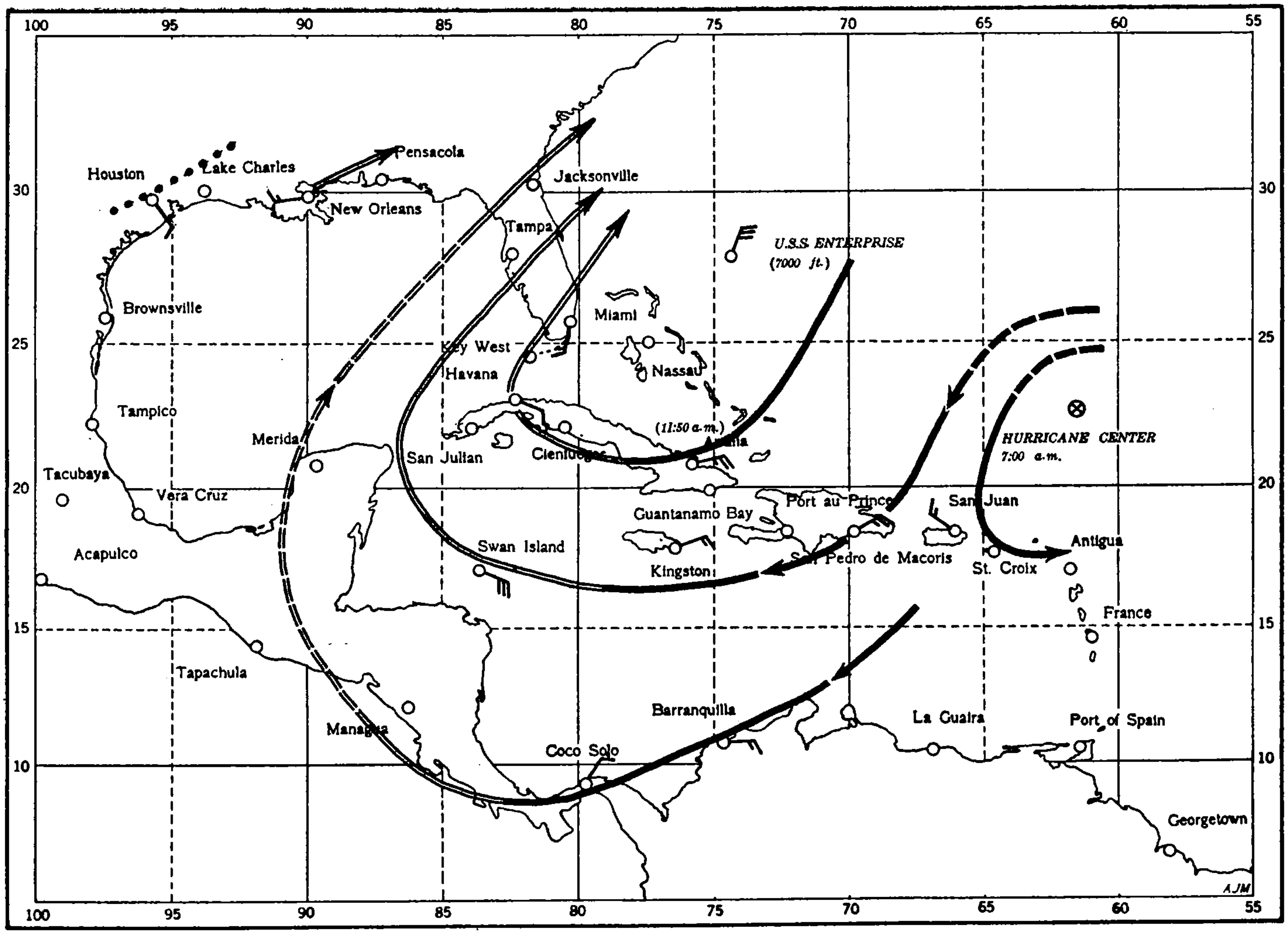

FIGURE 8.—Upper-air wind directions and velocities at the morning observation on September 18, 1938.

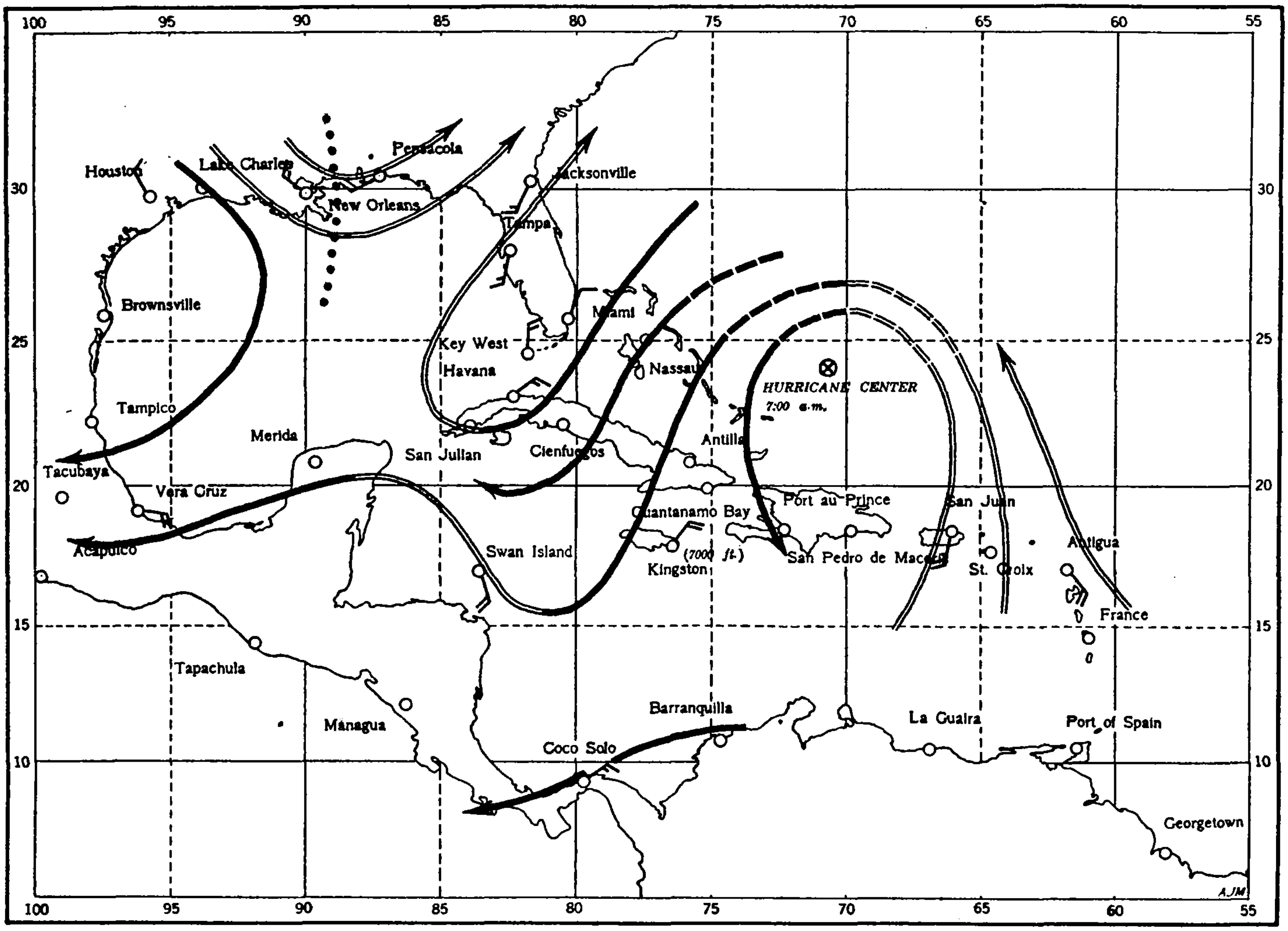

FIGURE 9.—Upper-air wind directions and velocities at the morning observation on September 19, 1938.

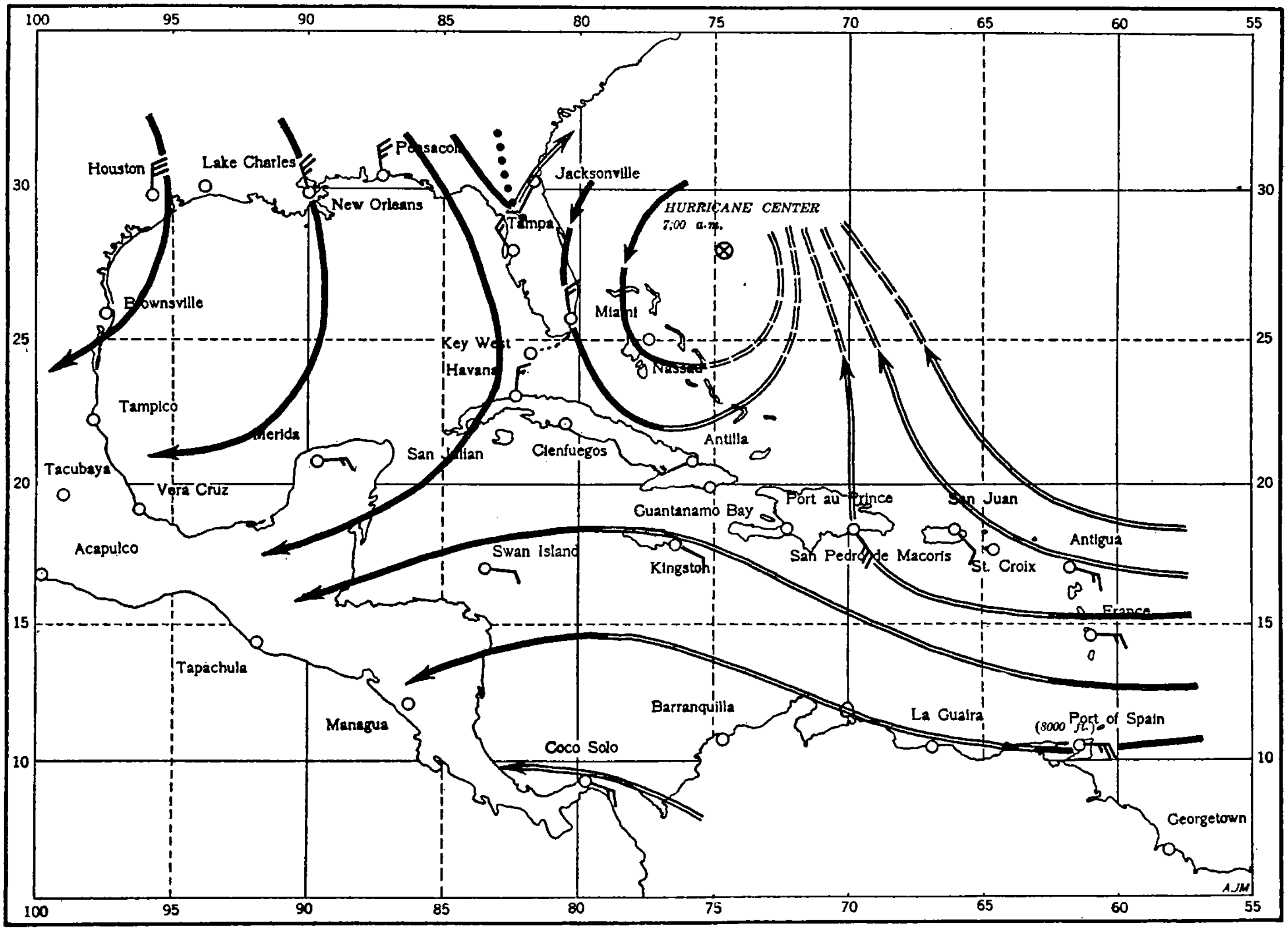

FIGURE 10.—Upper-air wind directions and velocities at the morning observation on September 20, 1938.

western United States has advanced east and south of New Orleans, La. The general aerological situation again indicates a recurve east of the Florida coast.

By the morning of September 20 the hurricane's recurving process from a west-northwest direction to north has almost been completed. The 10,000-foot chart shows conditions are returning to normal over the Windward Islands, while the hurricane circulation has pulled the northerly anticylconic circulation rapidly southeastward during the past 24 hours over the entire eastern Gulf of Mexico, completely wiping out the equatorial salient present there the day before, except near Jacksonville, Fla. Along the Atlantic coast north of Jacksonville, the tropical current remains to a great depth, Charleston, S. C., reporting altoculmulus and Cape Hatteras, N. C., cirrus, from the south.

In this paper no complete or rigorous analyses of the various upper-air charts have been attempted, nor have all the forces influencing the storms' directions of movement been enumerated. Rather, the purpose has been to point out the extent of the aerological information now available in the Tropics or semi-tropics south and east of the United States, and some of the possibilities of the use of pilot-balloon and other upper-air data in the hurricane warning service and the great need of a more comprehensive airplane or radio-meteorograph program in this region.

(1) Calvert, E. B. The Hurricane Warning Service and its Reorganization. National Research Council, *Reports and Papers of the 1935 Meeting of the American Geophysical Union*, pp. 117–121.

(2) Mitchell, C. L. West Indian Hurricanes and Other Tropical Cyclones of the North Atlantic Ocean. MONTHLY WEATHER REVIEW Supplement No. 24, p. 4.

(3) *Ibid*, p. 17.

(4) Bowie, E. H. Formations and Movement of West Indian Hurricanes, MONTHLY WEATHER REVIEW, April 1922, pp. 173–179.

(5) Scofield, Edna. On the Origin of Tropical Cyclones, *Bulletin American Meterological Society*, June 1938, pp. 244–256.

A DEW-POINT RECORDER FOR MEASURING ATMOSPHERIC MOISTURE

By C. W. THORNTHWAITE and J. C. OWEN

[U. S. Soil Conservation Service, Washington, September 5, 1940]

For many years an urgent need for measurements of evaporation from land surfaces (fields and watersheds) as well as from water surfaces has been felt by agronomists, hydrologists, and climatologists. Attempts at correlating observations from various types of evaporation pans and atmometers with the evaporation from natural surfaces have been made. Many empirical formulae have been derived for determining evaporation from water surfaces.

Not until recent researches in aerodynamics revealed the nature of turbulent interchange in the levels of the atmosphere near the ground was it possible to devise a method for measuring evaporation from both land and water surfaces. The method depends on the measurement of atmospheric moisture at two levels near the evaporating surface and the intensity of turbulent mixing between them. It has been described in detail in a number of recent publications.[1 2 3 4 5]

The method required an accurate means of measuring the concentration of moisture in the atmosphere. For that reason all of the familiar devices for measuring humidity have been tested and evaluated and some new ones developed; a detailed report on hygrometry of the atmosphere is in preparation and will be published elsewhere. It is the purpose of this note to describe a new dew-point recorder which may be adapted to the needs of other workers in meteorology and allied fields.

The simplest and one of the earliest methods of measuring the concentration of moisture in the atmosphere is to determine the dew point. Air is cooled until its moisture reaches the point of saturation; the temperature is then observed and the vapor pressure is obtained by referring to appropriate hygrometric tables. This method depends on the fact that the pressure of water vapor does not change as the air is cooled but remains the same until saturation is reached. The temperature at which the air becomes saturated is called the dew point.

[1] Thornthwaite, C. W. *Ecology* 21: 17–28, illus., 1940.

[2] Thornwaite, C. W., and Holzman, Benjamin. *U. S. Monthly Weather Rev.* 67: 4–11, illus., 1939.

[3] Thornthwaite, C. W., and Holzman, Benjamin. *Natl. Res. Council, Amer. Geophys. Union Trans., Ann. Meeting* 20: 680–686, illus., 1939.

[4] Thornthwaite, C. W., and Holzman, Benjamin. *Natl. Res. Council, Amer. Geophys. Union Trans., Ann. Meeting* 21: 510–511, 1940.

[5] Thornthwaite, C. W., and Holzman, Benjamin. *U. S. Dept. Agr. Yearbook 1941*. [In press.]

All types of apparatus for determining the dew point possess a surface—usually a polished metal mirror exposed to the air so that condensed moisture can be detected—that can be cooled several degrees below air temperature and whose temperature can be observed. The exposed surface is cooled slowly until condensation appears, at which time its temperature is observed. This temperature is the dew point.

The most familiar dew-point hygrometer is a modification by Alluard of an apparatus designed nearly a century ago by Regnault. It consists of a small rectangular metal box whose surface is silver plated and polished. The box contains ether which is vaporized and cooled as air is forced through it. The surface of the box is similarly cooled and the temperature at which dew is observed to appear and disappear upon it is determined from a sensitive thermometer suspended in the ether.

The principle of the dew-point hygrometer has been used in the design of an instrument, illustrated in figure 1, which will give a continuous record of the dew point of the atmosphere.[6]

The essential element of the instrument is a polished metal mirror whose temperature can be controlled at the dew point and recorded. A thin, polished, chrome-plated, copper disk (10) approximately the diameter of a dime is affixed to the end of a copper rod (11) which is inserted through a stopper (12) of low heat conductivity into a conventional thermos bottle (14) which contains a cooling medium such as water-ice with salt, or dry ice with or without alcohol. Heat is conducted downward along the

[6] A number of instruments for use in determining the moisture concentration of flue gases and the dew point of distillates or for use in controlling air-conditioning equipment have been described in the literature or in patent applications. They are designed for industrial uses and are not suitable for making meteorological observations. Following are a few selected references:

Frank, A. K. *Gen. Elect. Rev.* 41: 435–437, illus., 1938.

Hixson, Arthur W., and White, G. Edwin. *Indus. and Engin. Chem. Analyt. Ed.* 10: 235–240, 1938.

Johnstone, Henry Fraser. *Ill. Engin. Expt. Sta. Cir.* 20: 5–22, illus., 1929.

Stack, S. S. *Gen. Elect. Rev.* 41: 106–108, 1938.

Winkler, C. A. *Canad. Jour. Res. Sect. D, Zool. Sci.* 17: 35–38, illus., 1939.

Tomlinson, Malcolm Claire Weyant. Device for determining the condition of a gas. *(U. S. Patent No. 1,883,116.)* October 18, 1932.

Deniston, Robert F., and Hawthorne, Wendell P. Apparatus for determining the dew point of a vapor product. (*U. S. Patent No. 2,106,593.*) January 25, 1938.

Anderson, Samuel M. Fluid-conditioning method and apparatus. (*U. S. Patent No. 1,789,268.*) January 13, 1931.

Johnson, James Yate. Improvements for measuring the humidity of gases or gaseous mixtures. (*British Patent No. 317,306.*) August 12, 1929.

Griffiths, Ezer, and Campbell, Norman Robert. Improvements for hygrometric apparatus. (*British Patent No. 330,772.*) June 19, 1930.